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MULTIVALUE CONTROL SYSTEM AND METHOD FOR CONTROLLING A MULTIVALUE CONTROLLED SYSTEM

The present invention relates to a multivalue control system according to the definition of the species in Claim 1. Furthermore, the present invention relates to a method for controlling a multivalue controlled system according to the definition of the species in Claim 7 and a method for controlling a propeller power unit according to the definition of the species in Claim 12.

The starting point for control technology or for a control task is a system or a device for which a value that changes with time is to be influenced in a certain way. The value to be controlled is designated as the controlled variable, and the given system or device as the controlled system. The controlled variable is an output variable of the controlled system, and a measured value of the controlled variable is termed the actual value of same. The controlled variable is to be influenced in such a way that the controlled variable is equivalent to a desired quantity, which is called the setpoint value. The real actual value of the controlled variable is compared to the desired setpoint value, the corresponding deviation, a so-called system deviation, being supplied to a controller. Based on the system deviation, the controller generates a regulating variable, the regulating variable being an input variable of the controlled system.

Frequently, controlled systems are to be controlled in which several variables that vary over time, that is, several controlled variables, are to be influenced and thereby controlled. Such controlled systems are termed controlled multivalue systems or multivalue controlled systems. Examples of such multivalue control tasks are the following:

- propeller power units, such as turboprop power units for aircraft, in which the speed and the performance of a propeller are to be controlled,
- distillation columns, in which the liquid level and temperatures in the bottom and the top of the column are to be controlled, or
- air conditioning, in which the temperature and the humidity of a space are to be controlled.

The present invention relates to such multivalue control systems or controlled multivalue systems. In the following, when the present invention is described, using as an example the regulation of a propeller power unit, the present invention should not be considered to be limited to this special application, even if the present invention may be used in a particularly advantageous manner for this application. In such multivalue control systems, as a rule, there are interrelationships between the several controlled variables and the several correcting variables of such a kind that one correcting variable acts not only upon one but on a plurality of controlled variables. Furthermore, as a rule, nonlinearities occur between the several correcting variables and the several controlled variables. The interrelationships and the nonlinearities between the correcting variables and the controlled variables pose considerable difficulties for the design of a suitable controller, especially if an optimal control result is required over the entire operating range of the controlled system, and not only in the area of a preferred operating point of the controlled system.

Wade, Harold L.: "Inverted Decoupling: A Neglected Technique", Advances in Instrumentation and Control, Instrument Society of America, vol. 51, p. 357-369, 1996 and US Patent 5,4403,074 described a controlled multivalue system having a controlled multivalue system, the controlled multivalue system having

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several correcting variables as input variables and several controlled variables as output variables, having several comparators for ascertaining control deviations, having several controllers, to each controller one control deviation being able to be supplied as input variable, and having a conversion device whose input variables are the output variables made available by the controllers, the conversion device calculating the correcting variables for the controlled multivalue system at least from the output variables of the controllers. In Gräser, Axel: "Cross-Profile Control in the Paper Industry - Sensors and Actuators as Determining Elements of the Control Quality", Automatisierungstechnik, Oldenbourg Verlag, vol. 45, p. 271-281, 1997, a control method is made public that has decoupling of the individual loops and a compensation of the system coupling.

Using the multivalue control systems or methods for controlling a controlled multivalue system known from the related art, up to this point, it has not been, or only insufficiently been possible to control in a satisfactory manner controlled multivalue systems having interrelatinships and nonlinearities between the correcting variables and the controlled variables.

The present invention is based on the problem of creating an improved multivalue control system and an improved method for controlling a controlled multivalue system, especially for controlling a propeller power unit. The problem is solved by a multivalue control system according to Claim 1 and a method for controlling a controlled multivalue system according to Claim 7. The method for controlling a propeller power unit includes the features of Claim 12.

According to the present invention, the conversion device, when calculating the correcting variables, superimposes on the

output variables of the controllers an input control component that is a function of actual values of the controlled variables. Thereby is achieved a good decoupling of the correcting variables and the controlled variables of the controlled multivalue system, which is used for compensating for the system nonlinearity.

Preferably there is present a first controlled variable conversion device and a second controlled variable conversion device. The output variables of the controlled multivalue system, that is, the controlled variables, are able to be supplied to the first controlled variable conversion device as input variables, the first controlled variable conversion device ascertaining output variables, from the controlled variables, which are able to be supplied to the comparators as first input variables. Furthermore, the setpoint values of the controlled variables are able to be supplied to the second controlled variable conversion device as input variables, the second controlled variable conversion device ascertaining output variables, from the setpoint values, which are able to be supplied to the comparators as second input variables. The control result is optimized by the controlled variable conversion, and the structure of the control is considerably simplified.

Preferred refinements of the present invention are revealed by dependent subclaims and the following description.

An exemplary embodiment of the present invention is explained in greater detail in the light of the drawings, without being limited to this. The figures in the drawing show:

Figure 1 a closed-loop control circuit for a propeller power unit to clarify the multivalue control system

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according to the present invention and the method according to the present invention.

Figure 1 shows a multivalue control system 10 according to the present invention. The multivalue control system 10 shown in Figure 1 clarifies the present invention for an exemplary embodiment in which a controlled multivalue system 11, that is to be controlled, is developed as a propeller power unit of an aircraft. Although the present invention is particularly suitable for this application case, the control concept according to the present invention may also be applied to other controlled multivalue systems.

As shown in Figure 1, in the case of the controlled multivalue system 11 developed as a propeller power unit, a propeller speed n_P and a propeller performance P_{PR} are to be controlled as controlled variables 12, 13. The two controlled variables 12, 13 represent the output variables of controlled multivalue system 11.

Two correcting variables 14, 15 are supplied as input variables to controlled multivalue system 11 that is formed as a propeller power unit. In the case of first correcting variable 14, in the exemplary embodiment shown here, a propeller blade angle of incidence β is involved. In the case of second correcting variable 15, a fuel stream w_F is involved.

Thus, in the case of the propeller power unit, a controlled multivalue system 11 is involved, having two input variables and two output variables. There are close interrelationships and nonlinearities between the input variables, namely, correcting variables 14, 15 and the output variables, that is, controlled variables 12 and 13, of the controlled multivalue system 1 developed as a propeller power unit. With the aid of multivalue control system 10 according to the present

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invention and the method according to the present invention for controlling controlled value system 11, a solution is provided by which the interrelationships and the nonlinearities between correcting variables 14, 15 and controlled variables 12, 13 may be eliminated to the greatest extent possible, and consequently one may also achieve an optimized control result, using simple control structures, over a broad operating range of controlled multivalue system 11 that is to be controlled.

As was mentioned before, the speed of the propeller n_P is to be controlled as the first controlled variable 12, and the power of the propeller P_{PR} is to be controlled as the second controlled variable 13. Measured values of these controlled variables are designated as actual values. Now, it lies within the meaning of the control task that the actual values of controlled variables 12, 13 should be brought into agreement with corresponding setpoint values 16, 17 for the speed of the propeller and the performance of the propeller. Thus Figure 1 shows, as first setpoint value 16, a setpoint value for the propeller's speed n_{Psoll}, and as second setpoint value 17 a setpoint value for the performance of the propeller P_{PRsoll}.

According to the present invention, the actual values of controlled variables 12, 13 are not directly compared to setpoint values 16, 17 of the same. Rather, for both the actual values of controlled variables 12, 13 and for the corresponding setpoint values 16, 17, there is present in each case a controlled variable conversion device 18, 19.

A first controlled variable conversion device 19 is assigned to the measured actual values of controlled variables 12, 13. A second controlled variable conversion device 18, however, is assigned to the corresponding setpoint values 16, 17.

First controlled variable conversion device 19 ascertains output variables 20, 21 from the actual values of controlled variables 12, 13. Correspondingly, second controlled variable conversion device 18 ascertains output variables 22, 23 from setpoint values 16, 17. The output variables 20, 21 of first controlled variable conversion device 19 and output variables 22, 23 of second controlled variable conversion device 18 are supplied to comparators 24, 25 as input variables. In comparators 24, 25, the corresponding output variables 20, 21, 22, 23 of controlled variable conversion devices 18, 19 are offset against one another. We shall comment on this in greater detail below.

In advance, at this point, we wish to go into detail on the conversions of the actual values of controlled variables 12, 13 as well as their setpoint values 16, 17 that are executed in controlled variable conversion devices 18, 19. Thus, first controlled variable conversion device 19, to which, as input variables, controlled variables 12, 13 are supplied, that is, actual values of the propeller's speed n_P and the propeller's power P_{PR}, makes available two output variables 20, 21, which are calculated from the input variables of controlled variable conversion device 19 and from characteristics values of controlled multivalue system 11. Thus, in the exemplary embodiment shown, first controlled variable conversion device 19 outputs as first output variable 20 controlled variable 12, that is, propeller speed n_P,, as the first output variable. On the other hand, as second output variable 21, first controlled variable conversion device 19 outputs a quantity ascertained from the actual values of controlled variables 12, 13, namely, in the exemplary embodiment shown, an ascertained value of turbine output P_{LPT}. Accordingly, propeller speed n_P and propeller performance P_{PR} are supplied to first controlled variable conversion device 19 as input variables. As output variables 20, 21, controlled variable conversion device 19

outputs propeller speed n_P and turbine output P_{LPT}. In order to ascertain turbine output P_{LPT} from controlled variables 12, 13, one proceeds according to the following equation:

$$P_{LPT} = P_{PR} + n_P * dn_P/dt * \Theta * 4\pi^2$$

where

P_{LPT} = turbine output

P_{PR} = propeller performance

n_P = propeller speed,

dn_P/dt = the first derivative of the propeller speed ,

Θ = mass moment of inertia of the propeller power unit.

By using the above equation, output variables 20, 21 of the first controlled variable conversion device may simply be ascertained from controlled variables 12, 13 in first controlled variable conversion device 19.

In an analogous way, the above equation is also used in second controlled variable conversion device 18, in which output variables 22, 23 are calculated from setpoint values 16, 17.

In addition, a time delay device for the setpoint value of the propeller speed is also integrated into second controlled variable conversion device 18. Output variable 22 of controlled variable conversion device 18 thus corresponds to the setpoint value for propeller speed n_{Psoll} at a time delay of, preferably, 200 milliseconds. Because of this time-delayed passing through of the setpoint value for the propeller speed, the dynamic time delaying effect of the propeller power unit is compensated for.

At this time, we point out that output variables 20, 21 of first controlled variable conversion device 19 may also be

designated as auxiliary controlled variables, and output variables 22, 23 of second controlled variable conversion device 18 may also be designated as auxiliary setpoint values.

As was mentioned above, output variables 20, 21 of first controlled variable conversion device 19 and output variables 22, 23 of second controlled variable conversion device 18 are supplied to comparators 24, 25 as input variables. As shown in Figure 1, output variables 20, 22 of controlled variable conversion devices 18, 19 are supplied to a first comparator 24. In the exemplary embodiment shown, in this connection, the recalculated actual values and setpoint values for propeller speed n_P are involved. In comparator 24, a difference is formed between this auxiliary setpoint value for the propeller's speed and the auxiliary actual value for the propeller's speed, and from this, a control deviation 26 for the propeller's speed is calculated. The control deviation for the propeller's speed is designated in Figure 1 as n_{Perr}. In analogous fashion, in second comparator 25, a difference is calculated between output variable 23 of second controlled variable conversion device 18 and output variable 21 of first controlled variable conversion device 19. Accordingly, in the exemplary embodiment shown, in second comparator 25, a difference is ascertained between a calculated actual value of turbine output P_{LPT}, that is used as auxiliary controlled variable, and a correspondingly calculated setpoint value for this auxiliary controlled variable. A corresponding control deviation 27 between the actual value and the setpoint value of the turbine output used as auxiliary controlled variable is designated in Figure 1 as P_{LPTerr}.

Control deviations 26, 27 of auxiliary variables 20, 21 are supplied to controllers 28, 29, according to Figure 1. Control deviation 26 of auxiliary controlled variable 20 is supplied to first controller 28. In the case of control deviation 26

supplied to first controller 28, accordingly, a control difference is involved between auxiliary setpoint value 22 of the propeller roational speed and auxiliary actual value 20 for the propeller speed. Accordingly, first controller 28 is designed as a speed controller. First controller 28 ascertains an output variable 30 from control deviation 26. In the exemplary embodiment shown, in the case of output variable 30 a torque request ΔT is involved.

Analogously, control deviation 27 of auxiliary controlled variable 21 is supplied to second controller 29. Thus, in the case of control deviation 27, the difference is involved between setpoint value 23 and corresponding actual value 20 of turbine output P_{LPT} that is used as auxiliary controlled variable. As a result, second controller 29 is designed as a power controller. Second controller 29 ascertains an output variable 31 from control deviation 27. In the case of output variable 31 of second controller 29, in the exemplary embodiment shown, a power request ΔP is involved.

The two controllers 28, 29 may be designed, for example, as PID controllers. Determining suitable controller parameters is up to one skilled in the art, who is involved.

Output variables 30, 31 of controllers 28, 29 are not used directly as correcting variables for controlled multivalue system 11, but are rather supplied to a conversion device 32. Output variables 30, 31 of controllers 28, 29 are accordingly used as input variables by conversion device 32. Output variables 30, 31 are offset against each other in conversion device 32. Conversion device 32 ascertains correcting variables 14, 15 for controlled multivalue system 11 from output variables 30, 31 of controllers 28, 29 and from characteristics values of controlled multivalue system 11. In

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the exemplary embodiment shown, this means that torque request ΔT and power request ΔP are supplied as input variables to conversion device 32. From these two input variables, conversion device 32 ascertains propeller blade angle of incidence β and fuel stream w_F as correcting variables for propeller power unit 11. In this instance, one preferably proceeds according to the following model equations:

$$T = \beta^{E1} * n_P^{E2}$$

$$P = w_F^{E3} * n_P^{E4}$$

where

P = turbine output, output variable of the speed controller,

T = torque, output value of the power controller,

n_P = propeller speed

w_F = fuel stream, the correcting variable wanted

β = propeller blade angle of incidence, the correcting variable wanted

E1, E2, E3, E4 = exponents of the model.

According to a further aspect of the present invention, in conversion device 32, for ascertaining controlled variables 14, 15, not only are output variables 30, 31 of the two controllers 28, 29 offset against one another, but rather an input control component is additionally taken into consideration in conversion device 32. Accordingly, characteristics of controlled multivalue system 11 - in the current exemplary embodiment characteristics of the turbine and of the propeller are involved - are looped into the control paths of multivalue control system 10.

In this connection, in the exemplary embodiment shown, characteristics maps of the propeller and the turbine are taken into consideration. Such characteristics maps are obtained from the mathematical or system-dynamic modelling of controlled multivalue system 11, in the exemplary embodiment shown, of the propeller power unit.

As input variables, output variables 30, 31 of the two controllers 28, 29 and, in addition, the measured corresponding actual values that are used as input control components, are supplied to these characteristics maps, which are familiar to one skilled in the art, who is being addressed here. In output variables 30, 31 of the two controllers 28, 29, the respective input control component is added, and this sum is supplied to the corresponding characteristics map as input variable. In this connection, the following applies:

$T = f(\beta, n_P, \ldots)$ and $T = \Delta T + T_{ist}$

$P = f(w_F, n_P, \ldots)$ and $P = \Delta P + P_{ist}$

where

$f(\beta, n_P, \ldots), f(w_F, n_P, \quad)$ = characteristics maps,

T_{ist}, P_{ist} = input control components.

From this, it follows that:

$$\beta = f(\Delta T + T_{ist}, n_P, \ldots)$$

$$w_F = f(\Delta P + P_{ist}, n_P, \ldots)$$

This means that the characteristics maps are not only impinged upon by nominal or measured inputs T_{ist} and P_{ist}, but also by dynamically ascertained output variables of the two controllers 28, 29. Output variables 30, 31 of the two controllers 28, 29 are looped in by the characteristics maps

of controlled multivalue system 11, and thus undergo additional conversion.

Multivalue control system 10 described here and the method for controlling controlled multivalue system 11 thus includes the following three blocks:

According to a first block, the output variables of controlled multivalue system 11, that is, controlled variables 12, 13 as well as corresponding setpoint values 16, 17 for controlled variables 12, 13, are recalculated in controlled variable conversion devices 18, 19 into auxiliary controlled variables 20, 21 and so are corresponding setpoint values 22, 23 for the auxiliary controlled variables. According to a second block of the present invention, output values 30, 31 of controllers 28, 29 that are ascertained from control deviations 26, 27 of auxiliary controlled variables 20, 21 are supplied to a conversion device 32. In conversion device 32, correcting variables 14, 15 for controlled multivalue system 11 are formed from output variables 30, 31 of controllers 28, 29. According to a third block of the present invention, at least one input control component is superimposed on output variables 30, 31 of controllers 28, 29, in conversion device 32. This input control component is a function of the modelling of controlled multivalue system 11. In the case of the input control components, characteristics maps of controlled multivalue system 11 are involved, as the input variables for these characteristics maps the dynamically ascertained output variables 30, 31 of controllers 28, 29 and the measured corresponding actual values, so-called input control components being used.

While using the structure of multivalue control system 10, one may, in a simple manner, eliminate interrelationships between correcting variables 14, 15 and controlled variables 12, 13 of

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controlled multivalue system 11, as well as nonlinearities in the dynamic behavior of controlled multivalue system 11. The multivalue control problem of controlled multivalue system 11 may thus be attributed to decoupled, linear closed-loop control circuits having one input variable as well as one output variable. Using simple control laws, such as PID controllers, one may then implement a satisfactory control of controlled multivalue system 11 over the entire operating range of controlled multivalue system 11.

Multivalue control system 10 according to the present invention may be used with special advantage for controlling a propeller power unit. The pronounced nonlinearities in the dynamic transmitting behavior that occur in a propeller power unit, as well as the pronounced interrelationships between the correcting variables and the controlled variables of the propeller power unit are easily eliminated by using the present invention. With the aid of the controlled variable conversion according to the present invention, and the correcting variable conversion, propeller speed n_P and propeller performance P_{PR} may be controlled decoupled from each other and linearly, to a great extent. Using a simple set of control parameters, an optimized control of a propeller power unit may be achieved over the entire operating range of the propeller power unit. Multivalue control system 10 according to the present invention is distinguished by a robust control behavior.

List of Reference Numerals

multivalue control system	10
controlled multivalue system	11
controlled variable	12
controlled variable	13
correcting variable	14
correcting variable	15
setpoint value	16
setpoint value	17
controlled variables conversion device	18
controlled variables conversion device	19
output variable	20
output variable	21
output variable	22
output variable	23
comparator	24
comparator	25
control deviation	26
control deviation	27
controller	28
controller	29
output variable	30
output variable	31
controlled variables conversion device	32